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14. Abstract/Notes

Multiseasonal analysis of Landsat multispectral images in CCT format permitted the mapping of lithologic facies in the Pedra Branca Granite, using geobotanical associations, which occur in the form of variations in the density of "cerrado" vegetation, as well as the predominance of certain distinctive vegetation species. Dry season images did not show very good results in lithological differentiation due to anomalous illumination conditions related to the low solar elevation and the homogeneity in the vegetation cover, specially the grasses that become dry during this season. Rainy season image, on the other hand, allowed the separation of the lithological types, a fact that can be attributed to a greater differentiation among the geobotanical associations. As a result of this study, the muscovite-granite facies with greisenization zones, which are lithological control of important tin mineralization within the Serra da Pedra Branca Granite, were mapped. This methodology can be sucessfully applied to similar known granite bodies elsewhere in the Tin Province of Goiás.

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MULTISEASONAL AND GEOBOTANICAL APPROACH IN REMOTE DETECTION OF GREISENIZATION AREAS IN THE SERRA DA PEDRA BRANCA GRANITE, GOIÁS STATE, BRAZIL

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INTRODUCTION

The fact that geobotanical associations can be detected by remote sensing (Lyon, 1975; Bølviken et al., 1977; Lefèvre, 1980; Birnie and Francica, 1981; Darch and Barber, 1983) has open up ample perspectives in using this technique to help conventional methods in the mineral prospecting. This study shows the applicability of multispectral Landsat images for the discrimination of greisenization areas in the Serra da Pedra Branca Granite, which are lithological control of important tin mineralizations (cassiterite). The basic parameter that permitted the discrimination of these areas through orbital remote sensing data (in the form of computer compatible digital tapes) was the occurrence of specific geobotanical associations adapted to the zones of metasomatically altered rocks (albitized/greisenized muscovite-granites). These geobotanical associations are more evident in the enhanced Landsat image of the rainy season (summer), because in this time of the year better contrast occurs between the geobotanical anomalies and the normal vegetation cover of the area ("cerrado").

The Serra da Pedra Branca granite is located near the town of Nova Roma, Goiás state, which is approximately 400 km north of Brasília, in Central Brazil (Fig. 1). This region is dominated by a semi-humid climate with a summer rainy season (October to April) characterized by an average precipitation of 1500 mm and a dry winter (May to September). The mean annual temperature in the region is around 25°C. The native vegetation is a savanna type ("cerrado"), characterized by a sparse distribution of small trees with twisted

trunks and branches, some shrubs, and a continuous grass mat covering the soil. The grass is very sensitive to the soil moisture and becomes dry in the prolonged dry spell. However, soon after the first rain, the vegetation vigor recovers rapidly.

GENERAL CHARACTERISTICS OF THE SERRA DA PEDRA BRANCA GRANITE

Geology

The Serra da Pedra Branca Granite is a dome, 12 km long by 9 km wide, with an elevation around 500 meters. The granitic body is surrounded by gneisses and migmatites (Basement Complex) of Archean age, and by metasedimentary rocks of Middle/Late Proterozoic age (Araí Group). The contacts of the granitic body with the surrounding rocks are generally by faults. Preliminary Rb/Sr dating for the Serra da Pedra Branca Granite indicates values around 1600 million years (Hasui et al., 1981).

The Serra da Pedra Branca dome is formed by a biotite-granite which shows a grey to pink color and displays an overall medium to coarse grained texture, but locally includes porphyritic textures. The main geological characteristics of the granite has been described by Padilha & Laguna (1981). The granite experimented intense postmagmatic transformation processes which are represented by several facies varying from slightly albitized muscovite-granites to typical greisens. These rock types are strongly controlled by faults and fractures, showing cataclastics textures. The main region of occurrence of albitized muscovite-granites is located at the western portion of the granitic body in a basin like depression ("Bacia"), with dimensions

of 4 by 2 km. These are whitish to greenish grey, medium to fine grained rocks, in which quartz and feldspars (microcline and albite) appear as phenocrysts inserted in a fine matrix formed by micas (muscovite and zinnwaldite) and by those minerals above. Cassiterite, fluorite and topaz are the main accessory minerals. Typical greisens (quartz-mica composition) occur at fracture displacement gaps, as lenses that can reach lengths up to 100 meters. These metasomatic rocks are rich in cassiterite, thus constituting important tin deposits. Cataclastic processes which affected other portions of the granitic body developed extensive mylonite belts. These rock types are very similar in appearance to the albitized/greisenized zones, which in turn were also affected by the cataclasis, thus making the visual distinction between these rocks in the field very difficult.

Soils

The pedological development in the Serra da Pedra Branca Granite shows a straightforward relationship with the two main granite facies occurring in the massif. Thus, dark brown soils which are associated to the biotite-granite are relatively thinner, nutrient richer, and contain greater organic matter content than soils associated to areas of metasomatically altered rocks. In these latter mentioned areas occur whitish lithosols with an upper cap of sand and quartz fragments. Interspersed outcrops are found in shallow soils in these places. Table 1 shows some results of chemical analysis of samples obtained from these two types of soils. The soils derived from the alteration of the biotite-granite, besides being richer in organic

matter, have greater amount of total exchangeable bases and greater cation exchange capacity than the soils derived from the alteration of albitized/greisenized muscovite-granites.

Vegetation Cover

The characteristics of vegetation cover on the Serra da Pedra Branca Granite are controlled by the fertility of soils developed in the areas of biotite-granite and of albitized/greisenized muscovite-granites. In these areas distinctive features in the vegetation cover are expressed by: (a) variations in the "cerrado" characteristics, and (b) predominance of certain vegetation species better adapted to the local soil conditions. In areas of more fertile soils derived from the biotite-granite, the "cerrado" is represented by its typical feature: low and tortuously bent trees and grasses mat. On the other hand, in areas of albitized/greisenized muscovite-granites the trees become more sparse and less developed, where shrubs and grass are predominant. Fig. 2 shows these two vegetation cover types in the "Bacia" area. In areas where the metasomatic alteration processes were more intense, the soils are even more acid, allowing only the growth of grasses and a few of other very localized plants such as "canela-de-ema" *(Vellozia flavicans)* and the "barba-de-bode" grass *(Aristida pallens)*. This geobotanical association, shown in the Fig. 3, is specific to the areas of more intense albitization and greisenization processes.

ANALYSIS OF LANDSAT IMAGES. RESULTS AND DISCUSSION

Methodological Approach

Computer compatible magnetic tapes of Landsat-1 multispectral images, for the dry and rainy seasons, were used in this study. Only bands 5(0.6-0.7 μm) and 7(0.8-1.1 μm) were chosen since most of the information contained in the bands 4 and 6 are redundant with those of the 5 and 7 bands, respectively. Landsat images of the study area were acquired at a time immediately after the discovery of the cassiterite deposits, i.e. 1973. These Landsat passages were chosen so that later human activities around the deposits, such as removal of vegetation cover, could be avoided. The images were analysed in a Multispectral Image Analyser/Image-100 (GE, 1975), with a grey scale of 256 levels distributed between zero (black) and 255 (white). Both dry and rainy season images were enlarged at video scale of 1:75.000 and were corrected for noise effects and atmospheric scattering. Linear Contrast Stretch and Band-Ratio were the algorithms utilized.

The analysis of Landsat images started with band 5 since vegetation and bare soil show contrasting spectral behaviour in this channel. The first objetive was to characterize areas with different vegetation cover percentages, which could be representative of the geobotanical associations whithin the Serra da Pedra Branca Granite. In the band 5 the darkest tones (lowest gray level) would represent areas with dense vegetation cover, which correspond to the biotite-granite areas. On the other hand, the lighest tones (highest grey

level) would represent surface regions with greatest percentage of bare soil and sparse vegetation cover corresponding to the muscovite-granite zones. Thus, attempt to increase the contrast between these area was made by using a Linear Contrast Stretch of band 5 both in dry and rainy seasons.

Band ratioing between noncorrelated Landsat images are useful since they can show density variations within the vegetation covering the terrain (Raines et al., 1978). The ratio of band 7 by band 5 ($R_{7,5}$) is directly proportional to the vegetation density: areas with more dense vegetation will appear in light shades in the $R_{7,5}$ image, whereas those with sparse vegetation will show darker tones. Furthermore, ratio images permit to condense spectral information of two bands into a single product, which in turn is less dependent on the illumination conditions (Almeida Filho and Vitorello, 1981).

The products obtained with the use of Contrast Stretch and Band-Ratio techniques were analysed in conjunction with aerial photographies (1:60.000), topographic charts (1:50.000), light airplane reconnaissance, and successive field checking during winter and summer seasons.

Linear Contrast Stretched Images

A contrast stretched band 5 for the dry season of the Serra da Pedra Branca Granite is shown in Fig. 4. The analysis of this product shows that tonal variations observed in the enhanced image do not represent, in most of the cases, known regions where different

soil-vegetation associations occur within the granite body. Therefore this contrast stretched image contains little clear-cut geobotanical information. Even the broad "Bacia" composed of albitized muscovite-granite was not well defined by this enhanced product. The tonal variations in the image are mainly caused by the particular illumination conditions relating to the topography and the low sun elevation angle (30^o). During this time of the year, the topographic slopes facing the sun result in high gray tones in the image due to the intense frontal solar irradiation. On the other hand, the slopes facing away from the sun have dark areas because of the topographic shadowing. Besides the nonfavorable conditions of illumination, a weak geobotanical differentiation in the winter image of band 5 is attributed to the fact that all the grasses are dry at this time, and consequently less chlorophyll absorption occurs in this channel. This fact consequently results in a lesser contrast between areas with different vegetation cover percentages, which are responsible for the tonal variations observed in the Landsat band 5.

The linear contrast stretched band 5 image from the rainy season (Fig. 5) shows much better the vegetation cover differentiations adapted to the biotite-granite and albitized-greisenized muscovite-granite areas. A lighter area corresponding to the albitized muscovite-granite which forms the "Bacia" can be noticed at the western portion of the granitic body, while the remaining of the granitic body appears in darker shade. The distinction of the "Bacia" is possible in the rainy season because all forms of vegetation,

including the grasses, are vigorous in the zones of biotite-granite, at this time of the year. On the other hand, in areas of the muscovite-granite, soil moisture does not affect substantially the vegetation coverage, since the principal factor affecting the vegetation density is the soil acidity. At these areas of very acid soils, grasses are less developed and their associated "canela-de-ema" and "barba-de-bode" plants are not affected by seasonal variation. Besides the better vegetation differentiation in the rainy season, the higher sun elevation angle at this time of the year (46^{o} in this case) provides a more propitious illumination condition, although there remain some shadow areas where the relief is more accentuated. The shadow areas can only be minimized by using band ratio techniques.

Band-Ratio Images

While the enhancement by contrast stretch of band 5 of the rainy season was able to delineate with relative assurance the area of albitized muscovite-granites of the "Bacia", the product of ratio $R_{7,5}$ for the same season pointed out additionally other new areas of metasomatically altered rocks in the Serra da Pedra Branca Granite, which were not recognized. This was possible since $R_{7,5}$ image can show more clearly subtle density variations in the vegetation cover, and because this product is less dependent on the illumination conditions. In the ratio image the metasomatically altered rocks have been found with the grey level interval between 131 and 181. Fig. 6 shows the areas of geobotanical anomalies associated with the occurrence of albitized/greisenized muscovite-granites. These areas

were enhanced by a "Level Slicer" (GE, 1975) of the $R_{7,5}$ image and inserted as a theme over contrast stretched band 7. The use of the band 7 image as a background is necessary for better geographic localization of these anomalous areas, since ratio image subdues morphological features by minimizing shadowing effects.

The target area indicated by the number 1 in the Fig. 6 corresponds to the albitized muscovite-granite that forms the "Bacia". In this area, cassiterite and fluorite occur disseminated in the rock matrix and sometimes form concentration of economic value. In the target areas shown by the number 2 and 3 occur greisens in the form of lenses of several sizes, lodged in muscovite- and biotite-granites. These areas correspond, respectively, to the "Ārea Placha" and "Manchão dos Baianos" which contain the major known tin deposits of the Serra da Pedra Branca Granite. The area indicated by the number 4 corresponds to albitized muscovite-granite geologically identical to the "Bacia" region, although data in respect to the mineralization in this target area have not been completely analyzed at the present study. In the area 5 the presence of metasomatically altered rocks is scarce, although some mineralized greisens occur in the part near the "Manchão dos Baianos" area. The target areas indicated by number 6 are accompanying the extensive faults cutting across the granitic body in the NW direction. These areas are dominated by cataclastic rocks, which are formed by K-feldspar and quartz phenocrysts inserted in fine matrix formed by quartz, K-feldspar, plagioclase (oligoclase) and aggregates of green mica (zinnwaldite?) and sericite. Rare crystals of cassiterite can be observed in the rock matrix through thin sections.

This target area needs additional studies in order to define its real potential for mineralization. The target areas 7 and 8 include secondary cassiterite deposits in colluvial material originated from the "Bacia" area.

CONCLUSIONS

Digital Landsat images of the rainy season (summer) enhanced by computer permitted to distinguish areas with distinct vegetation cover densities, which correspond to geobotanical associations in zones of albitized/greisenized rocks with cassiterite. Since some of the target areas pointed out by this research were previously unknown, this study indicates new sites for future mineral prospecting in the Serra da Pedra Branca Granite.

The results show that Landsat-MSS images can potentially be used as a tool to complement and help traditional mineral prospecting methods. Hovewer, the utilization of these images must be preceded by judicious analysis which should consider the type of mineral deposit, its controlling factors, the physiographic characteristics of the region, the role of the ambiental variables, the time of the satellite pass, and the use of several computer enhancement techniques.

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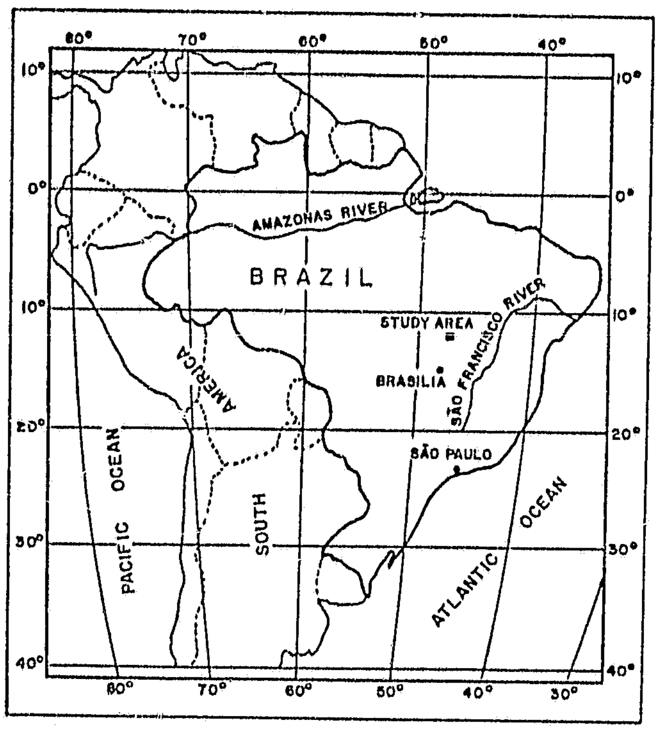

Fig. 1 - Geographic position of the study area.

Table 1 - Some chemical characteristics of the soils in areas of biotite-granite and of albitized/greisenized muscovite-granite.

Soil Samples	Parent rock	PH (H_2O)	Organic Matter	EXCHANGEABLE CATIONS				$\sum$	CTC
				Ca^{2+}	Mg^{2+}	K^+	Na^+	Bases	
			%	Meq/100g					
A	Biotite-Granite	5.20	2.40	0.70	0.10	0.40	0.04	1.24	4.24
B	Biotite-Granite	5.20	2.50	0.60	0.20	0.41	0.03	1.24	5.04
C	Muscovite-Granite	5.10	0.30	0.10	0.00	0.10	0.03	0.23	1.43
D	Muscovite-Granite	5.10	0.30	0.10	0.00	0.09	0.05	0.24	1.44

Fig. 2 - General view of part of the Serra da Pedra Branca Granite, showing the vegetation cover in biotite-granite (BG) and muscovite-granite (MG) areas, in the "Bacia" region.

Fig. 3 - Details of the vegetation in areas of intense metasomatic alteration characterized by the predominance of the "canela-de-ema" and "barba-de-bode" plants.

Fig. 4 - Linear contrast stretched Landsat band 5 for the dry season.

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Fig. 5 - Linear contrast stretched Landsat band 5 for the rainy season.

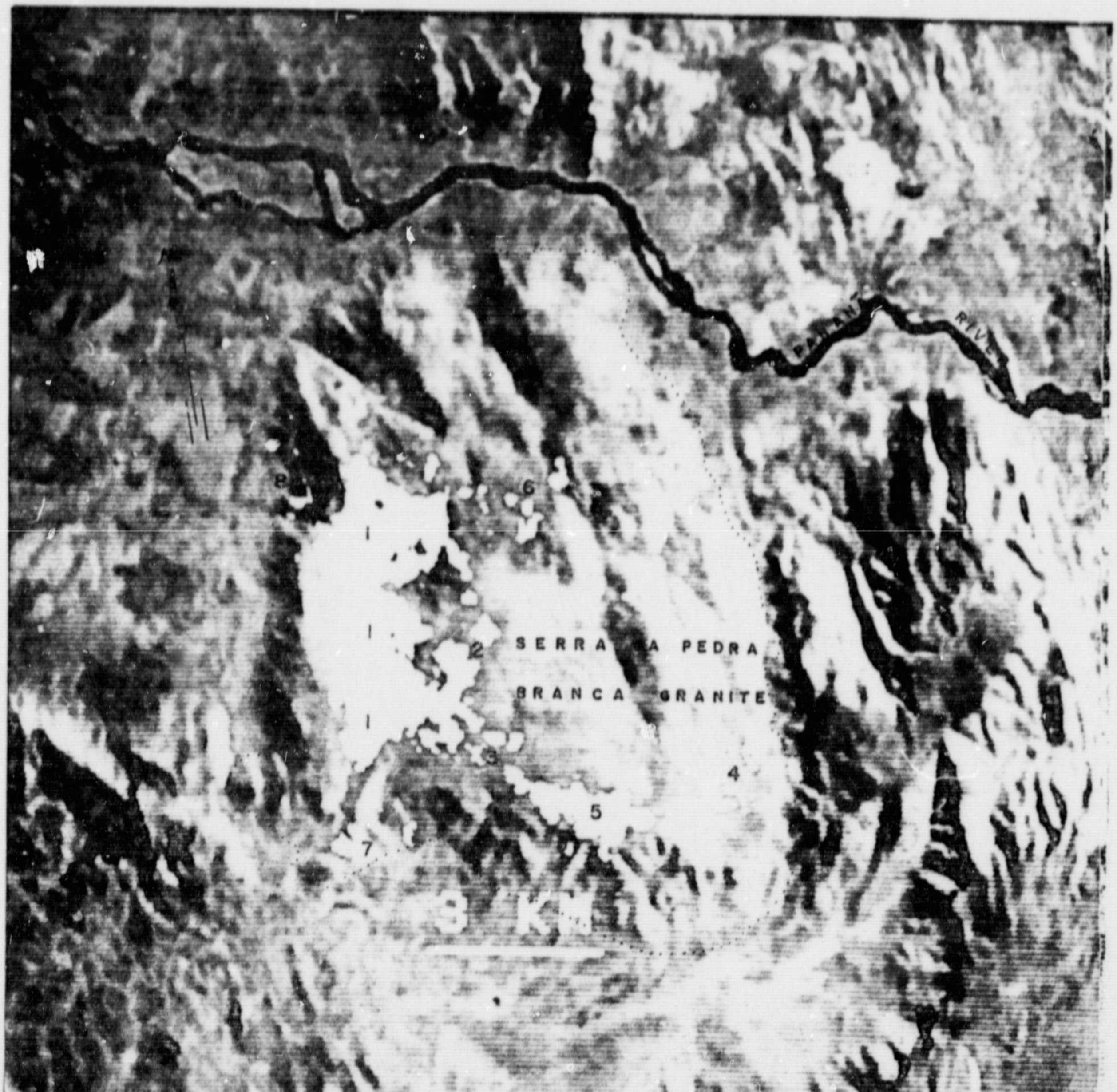

Fig. 6 - Geobotanical association indicating zone of albitized/ greisenized areas with cassiterite within the Serra da Pedra Branca Granite as shown by Landsat ratio image ($R_{7,5}$). The numbers correspond to target areas described in the text.